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AN EVALUATION OF GTAW-P VERSUS GTA WELDING OF ALLOY 718

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16. Abstract

Mechanical properties have been evaluated to determine statistically whether the pulsed current gas tungsten arc welding (GTAW-P) process produces welds in alloy 718 with room temperature structural performance equivalent to current space shuttle main engine (SSME) welds manufactured by the constant current gas tungsten arc welding (GTAW) process. Evaluations were conducted on two base metal lots, two filler metal lots, two heat input levels, and two welding processes. The material form was 0.125-inch (3.175-mm) alloy 718 sheet. Prior to welding, sheets were heat treated to either the ST or STA-1 condition. After welding, panels were left as welded or heat treated to the STA-1 condition, and weld beads were left intact or machined flush. Statistical analyses were performed on yield strength (YS), ultimate tensile strength (UTS), and high cycle fatigue (HCF) properties for all the post welded material conditions. Analyses of variance (ANOVA) were performed on the data to determine if there were any significant effects on UTS or HCF life due to variations in base metal, filler metal, heat input level, or welding process.

Statistical analyses have shown that the GTAW-P process does produce welds with room temperature structural performance equivalent to current SSME welds manufactured by the GTAW process, regardless of prior material condition or post welding condition.

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INTRODUCTION

Alloy 718 is a nickel-base precipitation hardenable alloy which was developed by the International Nickel Company in the 1950's. The alloy exhibits high strength and excellent corrosion resistance over the temperature range of −423 °F (−252.8 °C) to +1,300 °F (704 °C). This alloy is used extensively on the space shuttle main engine (SSME). Conventional GTA welding has been used in the manufacture of the SSME since the program began. The application of this process on alloy 718 through a range of thicknesses has provided an adequate method of joining both manually and automatically. The necessity for out-of-position welding and complex joint configurations for thicker cross sections (greater than 0.125 in (3.175 mm)) led to the investigation of a better method of heat input control.

In recent years, the automation of welding for engine fabrication has become a continuing effort for the purpose of improving weld quality and weld reproducibility. Quality control requirements are more easily met when using automated welding processes through the use of increased process control, decreasing the potential for human error. Automated welding provides the opportunity to pulse the weld current, enabling one to control freezing of the weld puddle, thus improving the ability to weld out of position, and to weld thicker cross sections.

Current pulsation, the act of cycling the arc current between a high and low value at the rate of a few cycles per second, provides molten weld puddle control [1] and increased penetration [1] for a given heat input. It has been shown, however, that increases in penetration are dependent on the current pulsing frequency [1,2]. Penetration depth increases linearly at frequencies between 3 and 10 Hz. The effect of this process variable on weld bead shape and solidification pattern led to a process characterization program involving mechanical property testing.

EXPERIMENTAL PROCEDURE

Welding and mechanical property testing for the GTAW-P/GTAW comparison study was performed primarily at the Marshall Space Flight Center (MSFC), Materials and Processes Laboratory facilities. Rocketdyne (RKDN), the primary contractor for the SSME, provided additional welded specimens representing current manufacturing practices for comparison purposes.

A. Weld Specimens

The program was conducted using two base metal lots, two filler metal lots, two welding power supplies, and two heat inputs. All welding was done in the flat position fixtured to eliminate weld peaking and mismatch as much as possible.

The base metals used in this study were commercial 0.125-in (3.175-mm) alloy 718 sheet per AMS5596C. The filler metals were 0.035-in (0.89-mm) and 0.045-in (1.14-mm) diameter alloy 718 wire per AMS5832B, for the MSFC and RKDN welded specimens, respectively. Heat/lot numbers for the base and filler metals are provided in tables 1 and 2. The shielding gas for MSFC welded specimens was 100-percent argon and for the RKDN welded specimens it was 95-percent argon/5-percent hydrogen.

The weld plan consisted of automatic GTA welding test panels of 0.125-in (3.175-mm) alloy 718 sheet. Two sheets 3 × 18-in (76 × 457-mm) welded together formed one weld panel. The weld joint was a square butt joint. Weld specimen populations consisted of the six groups of 6 × 18-in (152 × 457-mm) weld panels processed as described below:

Group A: Alloy 718 solution treated condition + GTAW-P (0.9-Hz) + post-weld heat treat to STA-1 condition (bead machined flush).

Group B: Alloy 718 solution treated condition + GTAW + post-weld heat treat to STA-1 condition (bead machined flush).

Group C: Alloy 718 STA-1 condition + GTAW-P (0.9-Hz) + "as welded" (bead intact).

Group D: Alloy 718 STA-1 condition + GTAW + "as welded" (bead intact).

Group RA: Alloy 718 solution treated condition + GTAW-P (10-Hz) + post weld heat treat to STA-1 condition (bead machined flush).

Group RC: Alloy 718 STA-1 condition + GTAW-P (10-Hz) + as welded (bead intact).

NOTE: (1) ST – solution treated condition consisted of a vacuum furnace solution anneal at 1,900 °F (1,038 °C) for 30 min followed by an argon quench.

(2) STA-1 – solution treated and aged condition consists of a vacuum furnace solution anneal at 1,900 °F (1,038 °C) for 30 min followed by an argon quench. The material is then age hardened at 1,400 °F (760 °C) for 10 hours, furnace cooled to 1,200 °F (649 °C), held at 1,200 °F (649 °C) for a time necessary to give a total of 20 hours for the 1,400 °F (760 °C) and 1,200 °F (649 °C) temperatures, and then cooled to room temperature.

RKDN weld specimen populations consisted of two groups (RA and RC) of weld panels identical in process sequence to groups A and C described above, except that the pulsing frequency was 10 Hz. Typical weld parameters for MSFC and RKDN weld specimens are listed in tables 1 and 2, respectively.

Nondestructive evaluations were performed according to RKDN specification RL10011 [3] and to MSFC-SPEC-560 [4]. Visual, fluorescent dye penetrant and radiographic inspections of welded panels met the class I quality requirements of RL10011. Mismatch and peaking measurements met the requirements of MSFC-SPEC-560.

The typical weld panel layout and identification code is shown in figure 1. Seven mechanical test specimens were machined from each welded panel: four were tensile specimens and three were fatigue specimens. One tensile and one fatigue specimen per panel were used for test machine set up.

Tensile testing was conducted at room temperature, according to American Society for Testing Materials (ASTM) E8 procedures, using a Tinius Olsen (DS-30) servohydraulic testing machine.

Axial fatigue testing was conducted at room temperature with a stress ratio of R = 0.05 (R = minimum stress/maximum stress). All testing was done on a 10k MTS Systems Corporation servohydraulic testing machine, using load control with a sinusoidal waveshape at an approximate frequency of 30 Hz.

Two maximum stress levels were used to generate the fatigue data. These were a stress level to generate approximately 10,000 to 50,000 cycles, and a stress level to generate approximately 1,000,000 cycles. Group A and B specimens were tested at stress levels of 110 ksi (758.45 MPa) and 66 ksi (455.1 MPa), respectively. Group C and D specimens were tested at stress levels of 83 ksi (572.3 MPa) and 50 ksi (349.3 MPa), respectively.

B. Structure Characterization

Representative test specimens were sectioned and mounted for metallographic review. Specimens were polished through 0.05 micron alumina, and the microstructure was revealed using Kallings etchant No. 2 which consists of 2 grams copper chloride ($CuCl_2$), 40-ml hydrochloric acid (HCL), and 40- to 80-ml ethanol (95 percent) or methanol (95 percent). Examination of the polished and etched surfaces was performed using light microscopy.

RESULTS AND DISCUSSION

A. Tensile Data

The mean and standard deviation for yield and ultimate tensile strength were calculated for each population. A summary of tensile data is shown in table 3. Weibull analyses [5] and student t analyses [6] were performed to compare significant differences in data for weld properties for yield strengths and ultimate tensile strengths. A summary of student t and Weibull analyses results are shown in tables 5 and 6, respectively. For all analyses, the results show that the GTAW-P welding process produces welds with equivalent or better room temperature yield strength and ultimate tensile strength than the GTA welding process.

Analyses of variance (ANOVA) [6] were performed on the MSFC weld panel tensile data to determine if there were any significant effects on the ultimate tensile strength due to variations in the base metals, filler metals, heat inputs, or welding processes (e.g., the factor/level combinations) used in the program. Analysis showed that for the "welded + STA-1" UTS data, there was a variation in the ultimate tensile strength due to changing the weld process or heat input, a slight change due to changing the base metal, and no change due to changing the filler metal. For the "as welded" UTS data, there was a variation in the ultimate tensile strength due to changing the weld process, base metal, or heat input, and no change due to changing the filler metal. The ANOVA analyses enabled us to quantify the magnitudes of the factor/level effects on the ultimate tensile strength of the data. An engineering assessment of these results show that while the statistical analyses showed effects due to weld process, heat input, base metal, or filler metal, the magnitudes of these results are not significant. A summary of all the ANOVA results is shown in table 7.

B. Fatigue Data

The natural logarithmic (LN) mean and standard deviation were calculated for each population for cycles to failure at various stress levels. A summary of fatigue data is shown in table 4. Weibull analyses and student t analyses were performed to determine significant differences in data for weld properties for the fatigue data. A summary of these results is shown in tables 5 and 6. For all analyses, the results show that the GTAW-P process produces welds with no distinguishably different room temperature high cycle fatigue life than the GTA welding process. The Weibull analyses results corroborated the student t results.

Analyses of variance were performed on the MSFC weld panel 110-ksi and 83-ksi fatigue data to determine if there were any significant effects on fatigue life due to variations in the base metal, filler metal, heat input, or welding process (e.g., factor/level combinations) used in the program. Analyses showed that for the "welded + STA-1" HCF data developed at the 110-ksi stress level, there was no variation in the fatigue life due to changing the weld process, heat input, base metal, or filler metal. For the "as welded" HCF data developed at the 83-ksi stress level, there was a variation in the fatigue life due to changing the base metal, and no variation in fatigue life due to changing the weld process, heat input, or filler metal. The ANOVA analyses enabled us to quantify the magnitude of these factor/level effects on the 110-ksi and 83-ksi fatigue life of the "welded + STA-1" and "as welded" data, respectively. An engineering assessment of these results shows that while the statistical analyses indicate effects due to base metal, the magnitude of these effects is not significant. A summary of all the ANOVA results is shown in table 7.

C. Metallography

Figure 2 (A and B) illustrates typical cross sections of MSFC specimens showing the two base metal lots. Significant differences in the base metal microstructures are seen, corroborating the ANOVA results which indicated variations in ultimate tensile strength and fatigue life between the two parent metals. Chemical analyses performed on representative test specimens of the two parent metal lots using x-ray fluorescence showed no difference in the chemical composition of the base metals.

Figure 3 (A through D) illustrates typical cross sections of weld population groups A, B, C, and D specimens. No significant microstructural differences were noted between the GTAW and GTAW-P welding process specimens for similar post-welded conditions (e.g., group A versus group B and group C versus group D specimens). However, minor microstructural differences were noted between the "welded + STA-1" and "as welded" (e.g., group A versus group C and group B versus group D) specimens.

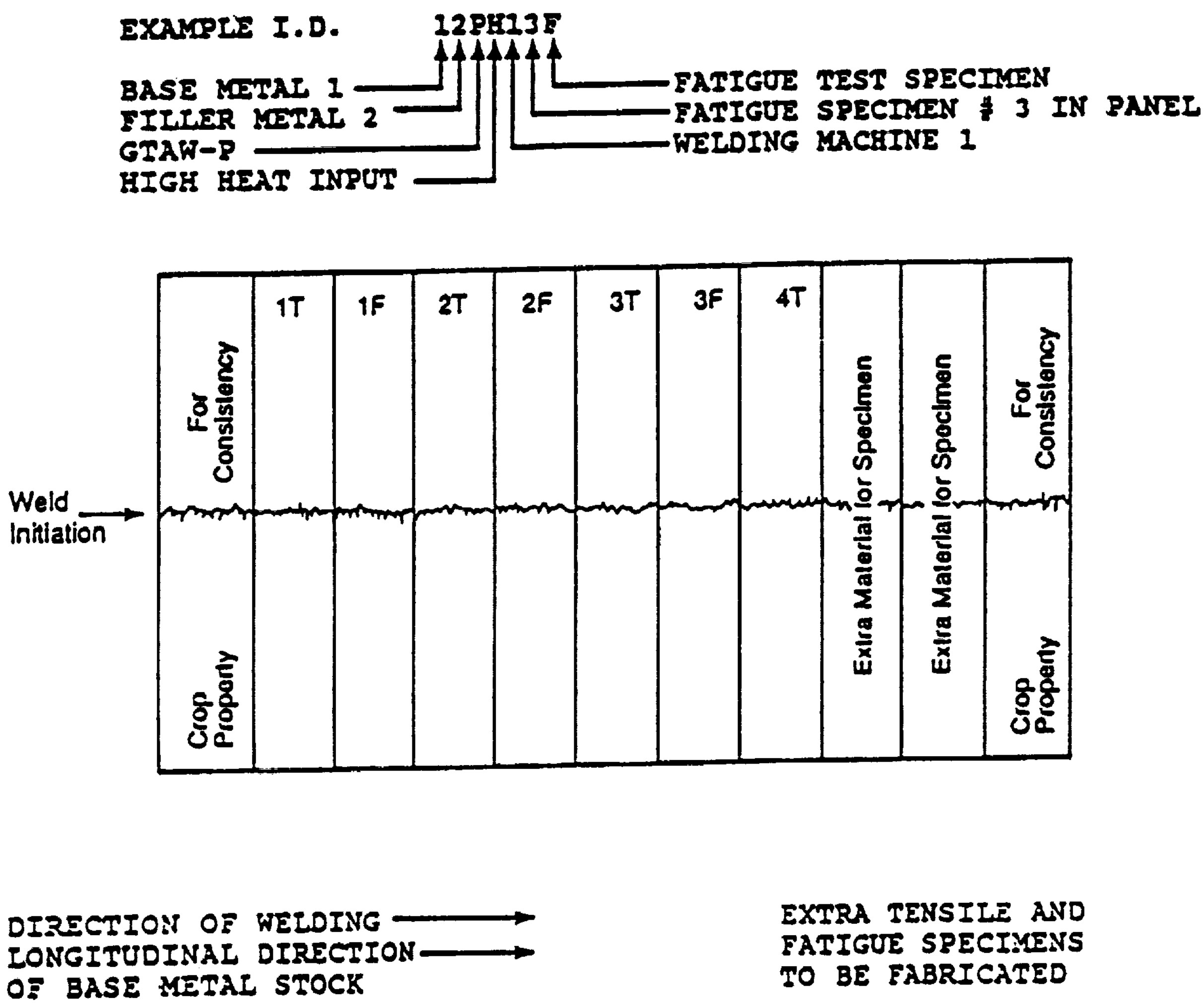
Representative MSFC weld panel specimens, welded at a pulsing frequency of 0.9 Hz, show a decrease in depth to width ratio when compared to the constant current welds. Representative RKDN weld panel specimens, welded at a pulsing frequency of 10 Hz, show a decrease in depth to width ratio when compared to MSFC constant current specimens. The noted effect is the same as observed by other investigators [1,2].

CONCLUSIONS

1. Pulsed current gas tungsten arc welding (GTAW-P) produces welds in alloy 718 with equivalent or better room temperature yield strength and ultimate tensile strength than the constant current gas tungsten arc welding (GTAW) process.

2. There is no distinguishable difference in the room temperature high cycle fatigue life of alloy 718 welds produced by the pulsed or constant current gas tungsten arc welding process.

3. Ultimate tensile strength and fatigue life are affected by different alloy 718 parent metal heat lots, alloy 718 filler metal heat lots, and heat inputs, but the magnitude of these effects is not significant.



SPECIMEN IDENTIFICATION (TRACEABILITY)	
BASE METAL:	1&2, (RECORD ACTUAL LOT NUMBERS)
FILLER METAL:	1&2 (RECORD ACTUAL SPOOL NUMBERS)
GTAW-P PROCESS:	P
GTAW PROCESS:	C
WELD MACHINE:	1&2 (SET-UP, POWER SUPPLY)
WELDING PARAMETER:	
0 HIGH HEAT INPUT:	H
0 LOW HEAT INPUT:	L
LAST DIGIT:	SPECIMEN NUMBER (LOCATION) IN WELD PANEL WITH NUMBERS INCREASING IN IN DIRECTION OF WELDING ON THE PANEL
LAST LETTER:	TEST REQUIREMENT
0 FATIGUE SPECIMEN:	F
0 TENSILE SPECIMEN:	T

Figure 1. Weld panel typical layout.

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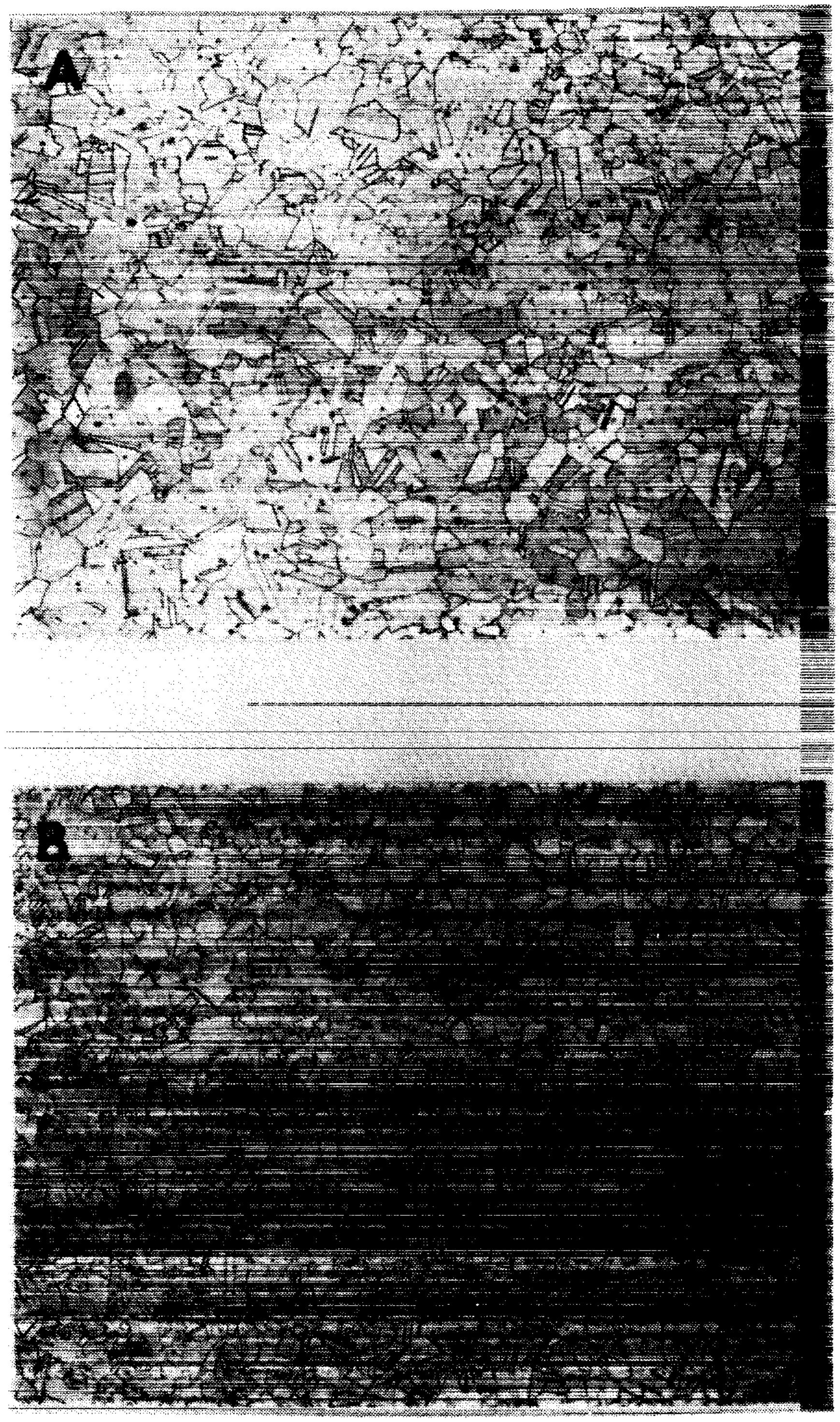

Figure 2. Typical cross sections of MSFC specimens showing base metal.

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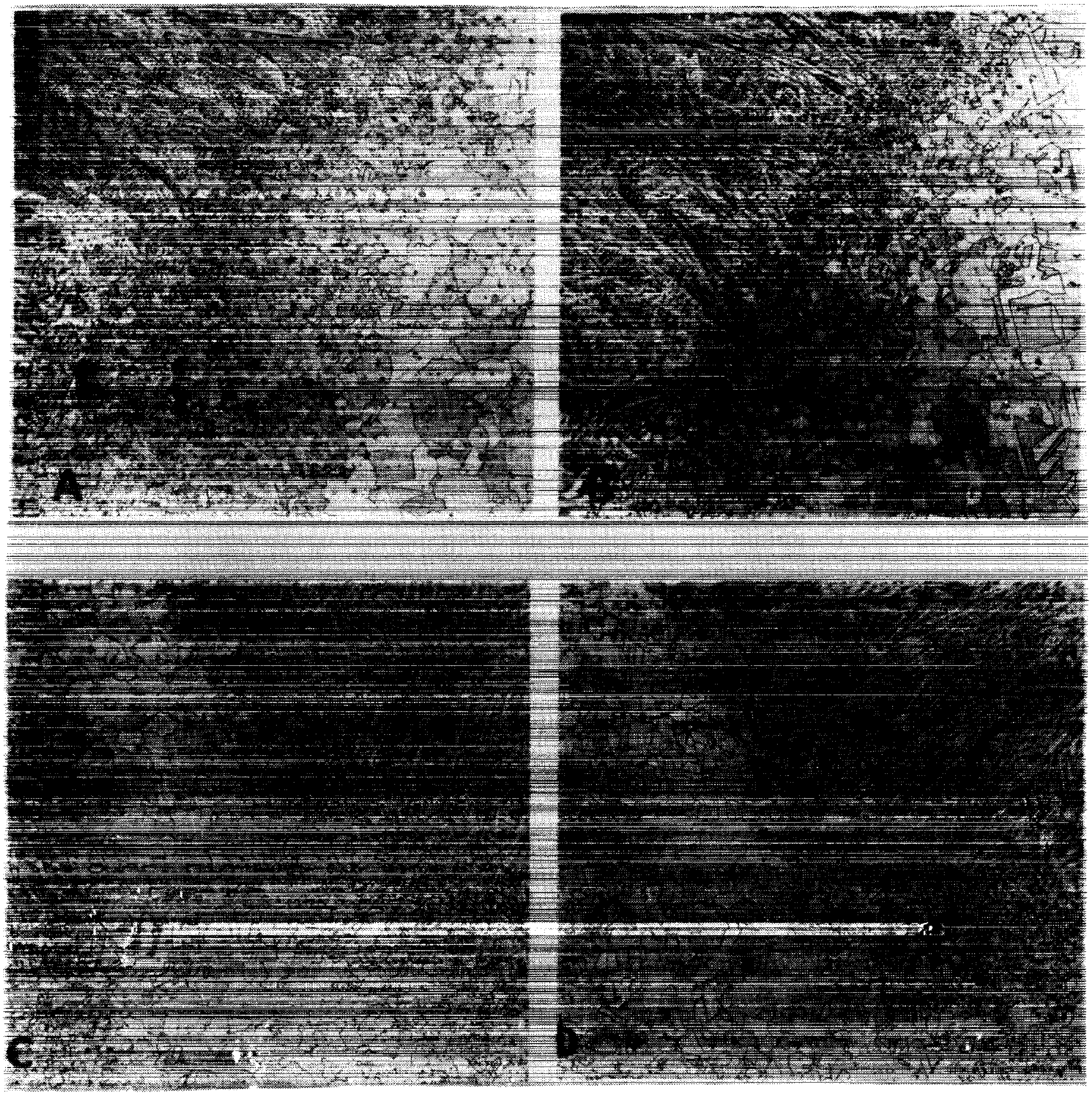

Figure 3. Cross sections of MSFC specimens showing microstructural features.

Table 1. MSFC specimens.

EP No.	84-032	Power Supply	Hobart Cyber Tig II
Date:	1/24/85	Torch Type/Cup Size	HW 27 / #12
Panel No.	NA, Typical Weld Parameters	Torch Attitude	3°
Current Type/Polarity	Pulse and Constant Current	Material/Thickness	718 Inconel/ .125
Electrode Type/Size	2% Thoriated/3/32	Joint	Square Butt
Electrode Conf.	30° Angle	Weld Position	Flat
Filler Metal Type/Size	718 Inconel/.045	Operator	
Shielding Gas Type/Flow	Argon/30 CFII		
Back-up Gas Type/Flow	Argon/5 CFII		

							Gas Data		
Weld Pass #	Initial Current, Amp	Weld Amp Current	Final Current, Amp	Travel Speed, IPM	Wire Feed Speed, IPM	Volts	Pre Flow Time, Sec	Post Heat Time, Sec	Post Flow Time, Sec
1	50	Pulsed 178–195	50	5	15	7.5	2	10	12
		C. Current 153–170							

				Pulse Data				
Weld Pass #	Up Slope Delay, Sec	Up Slope Time, Sec	Down Slope Time, Sec	Pulsation Delay, Sec	% Weld Current	Low Pulse Time, Sec	Hugh Pulse Time, Sec	Pulsation Stop Delay, Sec
1	2	5	10	0	55	.4	.5	1

Special Instructions: (1) Trailing Purge – 12 CFII/Argon; (2) Cleaning Process – Degrease, Power Brush With Stainless Steel, Wipe Clean With Alcohol.

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NOTE: Base Metals and Filler Metals Met The Chemical Composition Requirements of AMS 5596C and AMS 5832B, Respectively. Base Metal Heat/Lot Numbers Were HT31KSEY and HT67J4EK. Filler Metal Heat/Lot Numbers were BZ560 and H-92-9007013-AR.

Table 2. RKDN specimens, GTAW-P parameters.

Group	RA	RC
Material	Inconel 718	Inconel 718
Material Thickness	0.125 in (3.175 mm)	0.125 in (3.175 mm)
Material Condition	Solution Treated	Solution Treated
Joint Type	Square Butt	Square Butt
Filler Material	Inconel 718	Inconel 718
Filler Diameter	0.035 in (0.89 mm)	0.035 in (0.89 mm)
Weld Current	120 A	125 A
Background Current	50 A	50 A
Primary Volts	9.9 V	10.0 V
Background Volts	9.5 V	9.5 V
Pulse Frequency	5 Hz	5 Hz
Low Pulse Width	35%	35%
Travel Speed	3.5 IPM (1.48 mm/s)	3.5 IPM (1.48 mm/s)
Wire Speed	6.0 IPM (2.54 mm/s)	6.0 IPM (2.54 mm/s)
Torch Gas Type	95%Ar/5%H2	95%Ar/5%H2
Torch Gas Flow	25 CFM (708 L/Min.)	25 CFM (708 L/Min.)

NOTE: Base Metals and Filler Metals Met the Chemical Composition Requirements of AMS 5596C and AMS 5832B, Respectively. Base Metal Heat/Lot Numbers Were HT31KSEY and HT67J4EK. Filler Metal Heat/Lot Numbers Were BZ560 and H-92-9007013-AR.

Table 3. Tensile data summary.

Group	Mean (PSI/MPa)		STD. Dev. (PSI/MPa)		N
AUTS	182313	(1257)	3459	(24)	48
BUTS	180774	(1246)	4303	(29.7)	48
CUTS	133827	(923)	3604	(24.8)	48
DUTS	131784	(909)	3825	(26.4)	48
RAUTS	194361	(1340)	1567	(10.8)	16
RCUTS	129805	(895)	3315	(22.9)	15
AYS	160214	(1105)	2560	(17.7)	48
BYS	158550	(1093)	3508	(24.2)	48
CYS	79537	(548)	3006	(20.7)	48
DYS	79565	(549)	5939	(40.9)	48
RAYS	161234	(1112)	904	(6.2)	16
RCYS	77242	(533)	5811	(40.1)	15

Legend: (e.g., Auts, etc.)	
A:	Group A, MSFC Specimens
B:	Group B, MSFC Specimens
C:	Group C, MSFC Specimens
D:	Group D, MSFC Specimens
RA:	Group RA, RKDN Specimens
RC:	Group RC, RKDN Specimens
UTS:	Ultimate Tensile Strength
YS:	Yield Strength
N:	Number of Specimens

Note: One PSI = 0.006895 MPa.

Table 4. Fatigue data summary.

Group	LN Normal Mean	Std. Dev.	One SIGMA Range (Cycles)	N
A110	11.2153	.245526	(58091-94923)	16
B110	11.2794	.261273	(60969-102814)	17
C83	11.1142	.488295	(41188-109370)	16
D83	10.7913	.533779	(28496-82874)	17
RA110	11.0222	.383185	(41732-89804)	6
RC83	10.5423	.196985	(31110-46133)	4
A66	13.4342	.548657	(394566-1182163)	17
B66	13.6117	.628452	(435063-1529042)	18
C50	13.7663	.928655	(376113-2409560)	9
D50	12.7948	.966865	(137027-947578)	7
RA66	13.1121	.238218	(393518-633692)	5
RC50	14.3503	1.86079	(265537-10974555)	1

Legend: (e.g., A110, etc.)	
A:	Group A, MSFC Specimens
B:	Group B, MSFC Specimens
C:	Group C, MSFC Specimens
D:	Group D, MSFC Specimens
RA:	Group RA, RKDN Specimens
RC:	Group RC, RKDN Specimens
110:	Stress Level, KSI
83:	Stress Level, KSI
66:	Stress Level, KSI
50:	Stress Level, KSI
N:	Number of Specimens

Note: One KSI = 6.895 MPa.

Table 5. Student t analyses summary.

Group Compared	Results
AUTS/BUTS	Cannot Distinguish a Difference in Means at 95% Confidence
AYS/BYS	90% Confident AYS > BYS
CUTS/DUTS	95% Confident CUTS > DUTS
CYS/DYS	Cannot Distinguish a Difference in Means at 90% Confidence
AUTS/RAUTS	90% Confident RAUTS > AUTS
AYS/RAYS	90% Confident RAYS > AYS
BUTS/RAUTS	90% Confident RAUTS > BUTS
BYS/RAYS	90% Confident RAYS > BYS
CUTS/RCUTS	90% Confident CUTS > RCUTS
CYS/RCYS	Cannot Distinguish a Difference in Means at 90% Confidence
DUTS/RCUTS	Cannot Distinguish a Difference in Means at 90% Confidence
DYS/RCYS	Cannot Distinguish a Difference in Means at 90% Confidence
A110/B110	Cannot Distinguish a Difference in Means at 90% Confidence
A110/RA110	Cannot Distinguish a Difference in Means at 90% Confidence
B110/RA110	Cannot Distinguish a Difference in Means at 90% Confidence
A66/B66	Cannot Distinguish a Difference in Means at 90% Confidence
A66/RA66	Cannot Distinguish a Difference in Means at 90% Confidence
B66/RA66	95% Confident B66 > RA66
C83/D83	Cannot Distinguish a Difference in Means at 95% Confidence
C83/RC83	90% Confident C83 > RC83
D83/RC83	Cannot Distinguish a Difference in Means at 90% Confidence
C50/D50	Cannot Distinguish a Difference in Means at 95% Confidence
C50/RC50	Cannot Distinguish a Difference in Means at 90% Confidence
D50/RC50	Cannot Distinguish a Difference in Means at 90% Confidence

Legend: (e.g., Auts, A110, etc.)	
A:	Group A, MSFC Specimens
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RA:	Group RA, RKDN Specimens
RC:	Group RC, RKDN Specimens
UTS:	Ultimate Tensile Strength
YS:	Yield Strength
110:	Stress Level, KSI
83:	Stress Level, KSI
66:	Stress Level, KSI
50:	Stress Level, KSI

Note: One KSI = 6.895 MPa.

Table 6. Weibull analyses results summary.

Group	90% Confidence Life	90% Confidence Life
AUTS	L(10) = 177787 PSI	L(10) = 175906 PSI
BUTS	L(10) = 175149 PSI	L(10) = 172827 PSI
CUTS	L(10) = 125373 PSI	L(10) = 122271 PSI
DUTS	L(10) = 117542 PSI	L(10) = 112929 PSI
RAUTS	L(10) = 192103 PSI	L(10) = 191163 PSI
RCUTS	L(10) = 125294 PSI	L(10) = 123461 PSI
AYS	L(10) = 156834 PSI	L(10) = 155425 PSI
BYS	L(10) = 153855 PSI	L(10) = 151913 PSI
CYS	L(10) = 75632 PSI	L(10) = 74047 PSI
DYS	L(10) = 73685 PSI	L(10) = 71392 PSI
RAYS	L(10) = 159977 PSI	L(10) = 159452 PSI
RCYS	L(10) = 70074 PSI	L(10) = 67344 PSI
A110	L(10) = 44558 Cycles	L(10) = 33835 Cycles
B110	L(10) = 54113 Cycles	L(10) = 46105 Cycles
A66	L(10) = 344385 Cycles	L(10) = 258158 Cycles
B66	L(10) = 364940 Cycles	L(10) = 260064 Cycles
C83	L(10) = 33958 Cycles	L(10) = 25497 Cycles
D83	L(10) = 23152 Cycles	L(10) = 17040 Cycles
C50	L(10) = 380633 Cycles	L(10) = 190886 Cycles
150	L(10) = 102791 Cycles	L(10) = 53180 Cycles
RA110	L(10) = 33105 Cycles	L(10) = 25707 Cycles
RA66	L(10) = 338568 Cycles	L(10) = 288800 Cycles
RC83	L(10) = 28751 Cycles	L(10) = 25704 Cycles
RC50	L(10) = 77505 Cycles	L(10) = 26879 Cycles

Legend: (e.g., Auts, A110, etc.)	
A:	Group A, MSFC Specimens
B:	Group B, MSFC Specimens
C:	Group C, MSFC Specimens
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YS:	Yield Strength
110:	Stress Level, KSI
83:	Stress Level, KSI
66:	Stress Level, KSI
50:	Stress Level, KSI

Note: One KSI = 6.895 MPa.
One PSI = 0.006895 MPa.

Table 7. Analysis of variance results.

Effects of Weld Process, Heat Input, Filler Metal, and Base Metal on Ultimate Tensile Strength and Fatigue Lives of "Welded + STA-1 (Bead Machined Flush)" and "As Welded (Bead Intact)" Data

	Statistical Inference	Results Quantified	Engineering Assessment
EFFECTS	Tensile Data		
	Welded + STA-1 A & B		
	Weld Process – Yes	0.67 KSI	No Effect
	Heat Input – Yes	0.93 KSI	No Effect
	Filler Metal – No	0.39 KSI	No Effect
	Base Metal – Slight	0.53 KSI	No Effect
	As Welded C & D		
	Weld Process – Yes	0.82 KSI	No Effect
	Heat Input – Yes	0.34 KSI	No Effect
	Filler Metal – No	0.14 KSI	No Effect
	Base Metal – Yes	0.92 KSI	No Effect
EFFECTS	Fatigue Data		
	Welded + STA-1 (110 KSI) A&B		
	Weld Process – No	2130 Cycles	No Effect
	Heat Input – No	100 Cycles	No Effect
	Filler Metal – No	6797 Cycles	No Effect
	Base Metal – No	4403 Cycles	No Effect
	As Welded (83 KSI) C & D		
	Weld Process – No	6000 Cycles	No Effect
	Heat Input – No	200 Cycles	No Effect
	Filler Metal – No	4200 Cycles	No Effect
	Base Metal – Yes	15400 Cycles	No Effect

Note: One KSI = 6.895 MP_a

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APPROVAL

AN EVALUATION OF GTAW-P VERSUS GTA WELDING OF ALLOY 718

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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